UNIVERSITY TEKNIKAL MALAYSIA MELAKA

OPTIMIZATION OF MACHINING PARAMETERS IN CNC MILLING FOR NYLON 6

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process) with Honours.

by

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ABSTRACT

This report presents the analysis of the surface roughness for machined nylon 6 and optimization of machining parameters in 3-axis CNC milling for nylon 6 to obtain a good surface finish. Besides, determination the possible effect of CNC milling by conducting the surface roughness measurement on machined work pieces that produced by different parameters setting. Those parameters were cutting speed, feed rate and depth of cut. On the other hand, the response variable of this study was surface roughness. The setup of the experiment was based on the Response Surface Methodology (RSM) method. Furthermore, the surface roughness values were analyzed by using the Design Expert software. Total of 20 trials were conducted by using 3-axis CNC milling machine. Next, the surface roughness produced was checked by using surface roughness tester. From the results of this study, the surface finishing of the machined surface was influenced by the cutting speed and feed rate. High cutting speed and low feed rate produce the good surface roughness value. Furthermore, the optimum parameters in order to achieve the lowest surface roughness with the value of 0.379µm in this study are 106.81m/min cutting speed, 250mm/min feed rate, and 0.325mm depth of cut. However, the combination of low cutting speed and high feed rate result high surface roughness value. Then, a mathematical model, in term of those three machining parameters, has been developed for the response variable prediction using RSM based on the experimental results. The average deviation percentage of the mathematical model in this study is 21.56%.

ABSTRAK

Laporan ini membincangkan tentang analisis kekasaran permukaan untuk *nylon 6* dan pengoptimuman pembolehubah yang memproseskan *nylon 6* untuk mendapatkan permukaan yang baik. Mesin *3-axis CNC milling* digunakan dalam projek ini. Selari dengan itu, kesan-kesan yang mungkin disebabkan oleh pembolehubah daripada *CNC milling* adalah dikenalpasti dengan melakukan pengukuran kekasaran permukaan. Pembolehubah yang dikawal tersebut ialah *cutting speed*, *feedrate*, dan *depth of cut*. Selain daripada itu, kekasaran permukaan (*surface roughness*) adalah pembolehubah tidak terkawal dalam project ini. Segala penyediaan dalam experimen ini adalah disediakan oleh *Response Surface Methodology (RSM)*. Disamping itu, analisis kekasaran permukaan dijalankan dengan mengaplikasi perisian *Design Expert*. Daripada itu, sebanyak 20 kali eksperimen akan dijalankan dengan mengunakan mesin *3-axis CNC milling* bagi pengujian pembolehubah itu. Kekasaran permukaan daripada eksperimen itu akan diukur dengan menggunakan *surface roughness tester*. Daripada analisis keputusan yang telah dibuat, kekasaran permukaan telah dipengaruhi oleh cutting speed dan feed rate. Permukaan yang lebih licin boleh dicapaikan dengan menggunakan cutting speed yang tinggi sebanyak 106.81m/min, feed rate yang rendah dengan nilai 250mm/min dan depth of cut sebanyak 0.325mm. Tetapi, cutting speed yang rendah dan feed rate yang tinggi menghasilkan kekasaran permukaan yang tinggi. Seterusnya, model matematik adalah dikembangkan dengan menggunakan *RSM*. Nilai average deviation percentage badi model matematik adalah sebanyak 21.56%.

DEDICATION

To my beloved father and mother

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

AA	-	Arithmetic Average
ANOVA	-	Analysis of Variance
BUE	-	Built-Up-Edge
CLA	-	Center-Line Average
CNC	-	Computer Numerical Control
DOE	-	Design of Experiment
HSS	-	High Speed Steel
PA	-	Polyamide
Prob	-	Probability
RSM	-	Response Surface Methodology
Std. Dev.	-	Standard Deviation
R_a	-	Surface Roughness
µm	-	micro meter
m/min	-	meter per minute
mm	-	millimeter
mm/min	-	millimeter per minute
rpm	-	revolution per minute

CHAPTER 1

INTRODUCTION

This chapter explains the introduction of the title for the final year project and describes the problem faced by the CNC milling process. In addition, this chapter also includes objectives; scope and importance of carried this project. Finally, the result of this study was expected.

1.1 Introduction

Nowadays, the goal of modern industry is to manufacture low cost, high quality products in short time. Thus, the use of computer numerical control (CNC) machining centers has expanded rapidly through the years. And also automated and flexible manufacturing systems are employed for that purpose along with CNC machines that are capable of achieving high accuracy and very low processing time.

According to Yang and Lee (2001), a great help of the CNC machining is to reduce the skill requirements of human power. On the other hand, a regular shortcoming of CNC end milling is the operating parameter such as spindle speed, feed rate or depth of cut are prescribed conventionally either by a part programmer or by a relatively static database in order to preserve the tool. As a result, many CNC systems run under inefficient operating conditions.

According to theoretical models from Benardos and Vosniakos (2002), some of the parameters of the CNC milling process such as cutting force, feed rate, depth of cut, tool path (width of cut) will influence the machining results of the work piece. Besides, different types of the material and cutting tool also have an impact on cutting conditions, which is reflected on surface roughness, surface texture and dimensional deviations of the product.

Benardos and Vosniakos (2002) also stated that surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. The geometry of the machined surface plays an important role on the characteristics of the part such as appearance of excessive friction and/or wear. The achievement of a desirable value is a repetitive and empirical process that can be very time consuming.

Furthermore, Baltá-Calleja and Fakirov (2000) stated that the present tendency of industries is toward achieving increased material removal rates with high degree of automation, where the work piece best surface finish are prime importance. In order to obtain quality surface and closer tolerances, additional finishing operations, better control processing parameters, and the use of high quality equipment may be required.

Type of the cutting tool used in this study was M42 cobalt high speed steel. From the information of company HKM Equipments Supplier, this type of cutting tool was chosen because it has excellent resistance to abrasion and very good red-hardness for working difficult materials. Furthermore, the material used in this study was polymer, so that tool wear can be ignored.

On the other hand, the material used in this study was cast nylon 6. According to information from Hough and Dolbey (1995), cast nylon 6 has very good sliding properties and suitable apply in the classic material for slide bearings for heavily loaded machine parts. This includes bushings, slide and guide plates as well as gear and chain wheels. Due to the low coefficient of friction, a on its own lubrication at installation is usually adequate. In many cases, lubrication is not even necessary.

1.2 Background of Problem

Nowadays, numerous industry facing challenges to improve the quality of products with minimum cost and time constraints, stated by Chevrier et al. (2003). Besides, the set up of the parameter to achieve the good surface finish by using the "trial and error" method which is ineffectual and time consuming process. Normally, machinists and technicians have to set the parameters (speed, depth of cut, and feed rate) based on their experience by just eye inspection on the surface roughness after machining. Besides, this method is not effective for the work piece because it has several types of variables; hence low quality of the products is produced. Furthermore, the wrong setting of parameters such as depth of cut without guideline were shortening the cutting tool life and then poor surface integrity of work piece was produced. Moreover, the industrial also facing challenges to improve the quality of products and efficiency of production with minimum cost and time constrains. Hence there is a great need to investigate the effect of feed rate, cutting speed and depth of cut to the surface roughness by using Response Surface Methodology (RSM) method in order to get the best optimum parameter setting.

1.3 Problem Statement

Recently, nylon's broad size and shape availability combined with its excellent mechanical properties make it a widely used replacement material for materials such as bronze, cast iron and aluminum. Using nylon can reduce lubrication requirements and eliminate galling, corrosion and pilferage problems. However, during the machining process such as milling process, the removal chips melted on the cutting tool and work piece by using low cutting speed. According to the guideline from Kalpajian and Schmid (2006), stated that the highest possible cutting speed should be chosen to cut the nylon 6. Furthermore, different types of cutting tool have been created to cut plastics. But, the specific parameters such as cutting speed, depth of cut, and feed rate have to be decided according to the process of the work piece. Therefore a study in surface roughness was carried out to optimize the cutting parameters in order to get the best result.

1.4 Objective

The objectives of this paper are to:

1. To analyze the surface roughness of the machined nylon 6.
2. To optimize the machining parameters to achieve a good surface finish.

1.5 Scope

The focus of this study was on the cutting speed, feed rate, and depth of cut of the 3-axis CNC milling machine on the work piece by using the end-milling process. The material of the work piece was cast nylon 6 whereas the material for cutting tool was M42 cobalt high speed steel with diameter 6 mm. Aside from that, the surface roughness the machined work pieces was analyzed. On the other hand, the method used in this study was Respond Surface methodology (RSM). However, others responses such as residual stress, cutter geometry, chip formation, and tool wear would not be discussed in this study.

1.6 Importance of Study

The importance of this study was to recognize the effects of the parameters that influenced the surface finish of work piece. The study was also important to investigate the connection among milling machine and surface roughness. Therefore minimizing the failure of the process by controlling the parameters could help the industry to produce better quality products.

1.7 Expected Result

The surface finish was investigated by the Ra value which was measured by the surface roughness tester. Besides, by applying Design of Experiment (DOE) method on this experiment, the most influence parameters and relation between parameters and responses were analyzed.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the theory of milling machine and how the parameters were selected by referring from the journals. In addition, the basic principle of surface roughness is described in this chapter. Besides that, the machining, tool, work piece properties and summary of journals are also explained and illustrated in this chapter.

2.1 CNC Milling Machine

CNC Milling machine is a machine tool that able to perform versatile processes such as shaping, planning, and broaching of the metal and other solid material, in which the tool or work piece travel along a straight path, producing flat and shape surfaces. Besides, the cutter called end mill has either straight shank or a tapered shank is mounted into the spindle of the milling machine. Furthermore, Baltá-Calleja and Fakirov (2000) also declared that end mill can produce multiplicity types of surfaces at any depth such as curved, stepped and pocketed. For an example, in the study of Ramos et al.(2003) a different finishing milling strategy of a complex geometry part containing concave and convex surfaces was analyzed, the complex shapes of the blade was produced by using the end mill cutter through three types of cutting directions.

On the other hand, end milling process is one of the most important and common material cutting operation encountered for machining parts in manufacturing industry. By utilizing this process, the material can be easily removed from the surfaces of the work piece such as molds and dies. Since end milling process is the final stage in manufacturing a product, it is important to control the performance of this process.

2.2 Milling Parameter

Milling is a very complicated cutting process which involves many parameters such as cutting speed, feed rate, depth of cut, tool geometry, cutting force, etc. The most influential factors affecting the surface finish were studied by conducting a set of experiments. Shin et al. (2008) acknowledged that the factors considered for the experimentation were cutting speed, feed rate, and depth of cut. Besides, Liao et al. (2007) also emphasized that these three parameters are influence the cutting tool performance. Furthermore, in the research of Alauddin et al. (1995), the study was focus on the parameter of cutting speed, feed rate and depth of cut using response surface method (RSM). Therefore, in this study, it focused on these three main parameters and explained in detail.

2.2.1 Cutting Speed

The cutting speed is the edge or circumferential speed of a tool. In a machining center or milling machine application, the cutting speed refers to the edge speed of the rotating cutter. By referred the information of Seames (2002), proper cutting speed varies from material to material. Generally, the softer the work piece, the higher the cutting speed.

Moreover, excessive cutting speed will cause premature tool wear, breakages, and can cause tool chatter, all of which can lead to potentially dangerous conditions. Based on the information of Steve et al. (2006), said that using the correct cutting speed for the material and tools will greatly affect tool life and the quality of the surface finish.

By referred to Kalpajian and Schmid (2006), Cutting Speed (CS) Calculation is:

$$CS = \pi \times D \times N \text{---(1)}$$

Where

CS = cutting speed in surface meter per minute.

N = Rotational speed of the milling cutter, rpm.

D = diameter in mm of the cutter for milling machine.

2.2.2 Feed Rate

In the mention of Steve et al. (2006), feed rate is the velocity at which a tool is fed into a work piece. Feed rates used in milling not only depend on the spindle revolution per minute, but also on the number of teeth on the cutter. Also, feed rate is the velocity at which the cutter is feed against the work piece.

On the other hand, Seames (2002) pointed out that the feed rate calculation is:

$$F = R \times T \times rpm \text{---------------------------------------(2)}$$

Where

F = the milling feed rate expressed in inches per minute

R = the chip load per tooth

T = the number of teeth on the cutter

rpm = the spindle speed in revolutions per minute

Furthermore, Steve et al. (2006) stated that milling feed rates are also affected by some of the factors such as machine, setup rigidity and part geometry.

2.2.3 Depth of Cut

Depth of cut implements how much deep to cut per times and to get a smooth, accurate finish surface; it is good to take roughing and finishing cuts. Roughing cuts should be deep, with a feed as heavy as the work and the machine will permit. However, Steve et al. (2006) acknowledged that for heavy cuts may be taken with helical cutters having fewer teeth since they are stronger and have greater chips clearance. Finishing cut should be light, with finer feed than is used for roughing cuts. When fine finish is required, the feed should reduce rather than the cutter speeded up; more cutters are dulled by high speeds than by high feeds.

2.3 Material

The material used in this study is cast nylon 6 with heat stabilized. Nylon is a type of thermoplastics, and also called as engineering plastics. The research of Alauddin et al. (1995) declared that "Engineering plastics" are those high-performance plastics that provide multiple engineering properties at an economically feasible cost and can be processed without unusual measures.

From the article of Hoffman (2000), at the present time, nylon is one of the most misleading materials in the industry. In the beginning, the name was used by DuPont to describe a family of polyamides (PA) the company developed back in the 1930's. These materials, also referred to as PAs, were an advance in man-made materials. After a short period of rapid development, they became the first engineering thermoplastics to have a highly desirable crystalline structure. Therefore, the suitable nylon was chosen for a particular application.

Incessantly, the family of nylons consist of a number of different types, some of the most common being nylon 6, 6/6, 11, and 12, stated by Hoffman (2000). The first material commercially produced in 1939 by the DuPont plant in Seaford, Del., and given the trade name "nylon," was actually polyhexamethylene adipamide. It was also known as nylon 6/6 for the presence of six carbon atoms in each of its two molecules or monomers.